DIRECT ACOUSTIC TEST OF QUIKSCAT SPACECRAFT

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ABSTRACT

force

A direct acoustic test was performed on the QuikSCAT spacecraft at Ball Aerospace Technology Corporation (BATC) in Boulder, Colorado, in October 1998. The QuikSCAT spacecraft was designed and built by BATC in an accelerated, one-year, program managed by the NASA Goddard Space Flight Center. The spacecraft carries the SeaWinds scatterometer developed by the Jet Propulsion Laboratory to measure the near-surface wind speed over Earth's oceans. Instead of conducting the acoustic test with the spacecraft in a reverberant room, as is the usual practice, the test was conducted with the spacecraft mounted on a shaker slip-table in a nearly anechoic, vibration test cell. The spacecraft was surrounded with a three-meter high ring of large, electro-dynamic speakers, spaced approximately 1.3 meters away from the two-meter diameter, 900 kg. spacecraft. The thiry-one speaker cabinets were driven with 40,000 rms watts of audio amplifier power. The acoustic specification, with an overall sound pressure level of 135 dB, was achieved one meter in front of the speakers. Many acoustical issues may be raised concerning such a test and how it compares with a conventional reverberant-field acoustic test, e.g., the maximum obtainable levels and spectrum, the spatial and frequency uniformity, the efficiency of a normal-incidence direct field vs. a reverberant field in the

excitation of structures, and the importance of the spatial coherence of the acoustic field. However, it should be recognized that the conventional reverberant acoustic test is also an inexact representation of the actual flight acoustic environment, which consists of progressive waves coming from a select range of angles.

INTRODUCTION

On November 19, 1997 NASA Goddard Space Flight Center awarded BATC a contract for the QuickScat scatterometer replacement mission. BATC would provide the spacecraft bus, launch interface system, system integration, test, launch support, and two year mission operation. The contract represented the first mission for NASA under its new Rapid Spacecraft Acquisition (RSA) process. The QuickScat mission was to replace the June 1997 satellite failure of Japan's Advanced Earth Orbiting Satellite (ADEOS). The payload, a scatterometer sensor, was provided by the Jet Propulsion Laboratory (JPL). The JPL scatterometer sensor records sea-surface wind speed and direction data for long-term global climate research.

BATC's spacecraft product was specifically designed for remote sensing missions and very little change was required to accommodate the QuickScat mission. Therefore, BATC was able to propose a very aggressive schedule, with a start-to-launch period of less than twelve months. This allowed BATC to immediately begin procurement of materials and manufacturing of the bus began while JPL completed the flight spare scatterometer sensor from the ADEOS mission.

By August of 1998, as the spacecraft was nearing completion of integration, efficiencies were required to meet the November 1998 launch date. The time allotted to transporting the spacecraft to a remote site to conduct a traditional reverberant acoustic test was significant and was identified as a schedule driver. As an alternative, it was proposed to perform a "direct field" acoustic test in BATC's facility and thereby preserve the launch schedule. The spacecraft test would be performed without leaving the integration facility and one to two weeks of schedule would be recovered. The program management embraced this concept and a feasibility demonstration was commenced. The required acoustic test spectrum is shown by the triangle symbols in Figure 1.

ACOUSTIC TEST

A number of audio specialists were contacted and Audio Analysts Inc. (AAI) of Colorado Springs, Colorado was selected to provide the sound system and audio engineering services for the feasibility test. During the first week of September 1998, two sets of four speaker cabinets, configured as shown in Figure 2, were installed in one of BATC's vibration test cells. The cell was constructed with high transmission loss panels. Measurements of the fall-off of the sound pressure level (SPL) with distance from a simple acoustic source indicated that the cell was nearly anechoic for distances up to 84 ~~inches from the speakers, over the entire frequency range of the acoustic test. Thus,~~

inches from the speakers, over the entire frequency range of the acoustic test. Thus, reverberation provided no help in attaining the required levels. With the 8 speakers configured as in Figure 2 and arranged to occupy one quadrant of a circle, it proved feasible to generate the required acoustic spectrum at a microphone located approximately 42 in. in front of the speakers. In addition, a safety survey showed that the acoustic levels in the high-bay and offices adjacent to the test cell would be annoying, but not hazardous, during the full level run. Thus it was determined to proceed with the spacecraft acoustic test, with the full-level test to be conducted at night, to avoid disturbing workers in the surrounding offices.

TEST RESULTS

By the first week of October 1998, thirty-one speaker cabinets and the QuickScat spacecraft were installed in BATC's vibration facility for the first ever direct field acoustic test of a spacecraft. (An immovable object prevented the use of a 32nd speaker.) One of the problems in a direct field acoustic test such as this is balancing the requirements for achieving the required levels, which necessitates being close to the source, with the desire to achieve uniform acoustic coverage of the test item, which requires being far away from the source. In the acoustic direct field, the acoustic levels fall-off 6 dB every doubling of distance from a point source. However, the directivity of the tweeters shown in Figure 2 was such that their total spreading angle was only about 30 degrees, so it was not practical to place the speakers too close to the spacecraft. The final configuration of speakers selected for the QuikSCAT spacecraft acoustic test is shown in plan view in Figure 3 and in elevation view in Figure 4. The speaker cabinets are arranged in a circle with their front surfaces on a 84 inch radius. Eight microphones are spaced at 45-degree intervals on a 42-inch radius, at an elevation of 82.5 inches, which corresponds, to the center of the two-speaker stack shown in Figure 2. This arrangement provided good acoustic coverage of the spacecraft bus and solar panels, but did not provide uniform coverage of the top and bottom of the spacecraft. Since the solar panels of the spacecraft are located approximately 36 inches from the center, there was only about 6 inches between the microphones and the panels. Figures 5 and 6 are photographs of the QuikSCAT spacecraft being installed on the shaker table in the vibration test cell.

During a series of low level runs, the average of the eight equally spaced microphones shown in Figures 3 and 4 were computed and the spectrum was adjusted to the desired specification shown in Figure 1. The results for the full-level test are shown in Figure 7, which compares the data for the 8 individual microphones with their average and with the test specification. The shortfall of about 3 dB above 200 Hz was due to an error in interpreting the specification, but the levels are within the tolerance band. In future tests, this deficiency can easily be rectified, as the acoustic spectra was purposefully attenuated above 200 Hz. The shortfall below 50 Hz was due to a limit in the low frequency capability of the sound system and perhaps to the acoustical characteristics of the test cell. Figure 6 shows the scatterometer on top of the spacecraft protruding out through a hole in the ceiling of the test cell. It was anticipated that the levels would be scatterometer had received it's own acoustic test. However, in the complete installation, a penthouse was constructed over the scatterometer, to prevent high noise levels in the surrounding high bay. A rover microphone used during low-level tests showed a local acoustic resonance in the penthouse, so that the levels up there were actually higher than the spacecraft acoustic specification, but no higher than the acoustic levels to which the scatterometer had been previously qualified.

There were two other concerns regarding the direct field type of acoustical test: 1. phasing of the speaker drive signals, and 2. the relative efficiency of direct, normal acoustic waves in exciting the spacecraft structure, as compared to a reverberant field. The first concern was somewhat mitigated by the rapid decay of the levels with distance from the speakers and the relatively large size of the spacecraft. This combination resulted in very little interaction of the various speakers, particularly at the higher frequencies. To further mitigate the interaction, the electric signals into each of the four quadrants of speakers were delayed.

With regard to the concern regarding acoustical efficiency, it is known that a normal incidence wave is more effective in exciting low frequency modes of a panel than is a reverberant field. To illustrate this, Figure 8 shows the maximum response of a solar array shield, on another spacecraft, calculated with a boundary element code for a normal (z), a grazing (x), and a reverberant field. The maximum response, of what happens to be the 2^{nd} bending mode of the panel/shield combination at approximately 43 Hz, occurs for the normal wave and the minimum response for the grazing wave. Alternately, it is known that the reverberant field is more effective in exciting high frequency vibrations, because of acoustic and panel bending wavelength coincidence effects. Before the QuikSCAT acoustic test, a number of experts were polled and asked if we should adjust the acoustic spectrum for this relative efficiency effect. However, there was no consensus, so no adjustment was made in this test to account for the acoustical excitation efficiency.

CONCLUSIONS

The QuikSCAT direct field acoustic test was thought to be very successful. Because the direct acoustic test is very attractive from a cost, schedule, and logistics viewpoint, particularly for companies, which do not have an acoustic test facility, it may be utilized in many future spacecraft programs, in which the acoustic environment is not too severe.

ACKNOWLEDGMENTS

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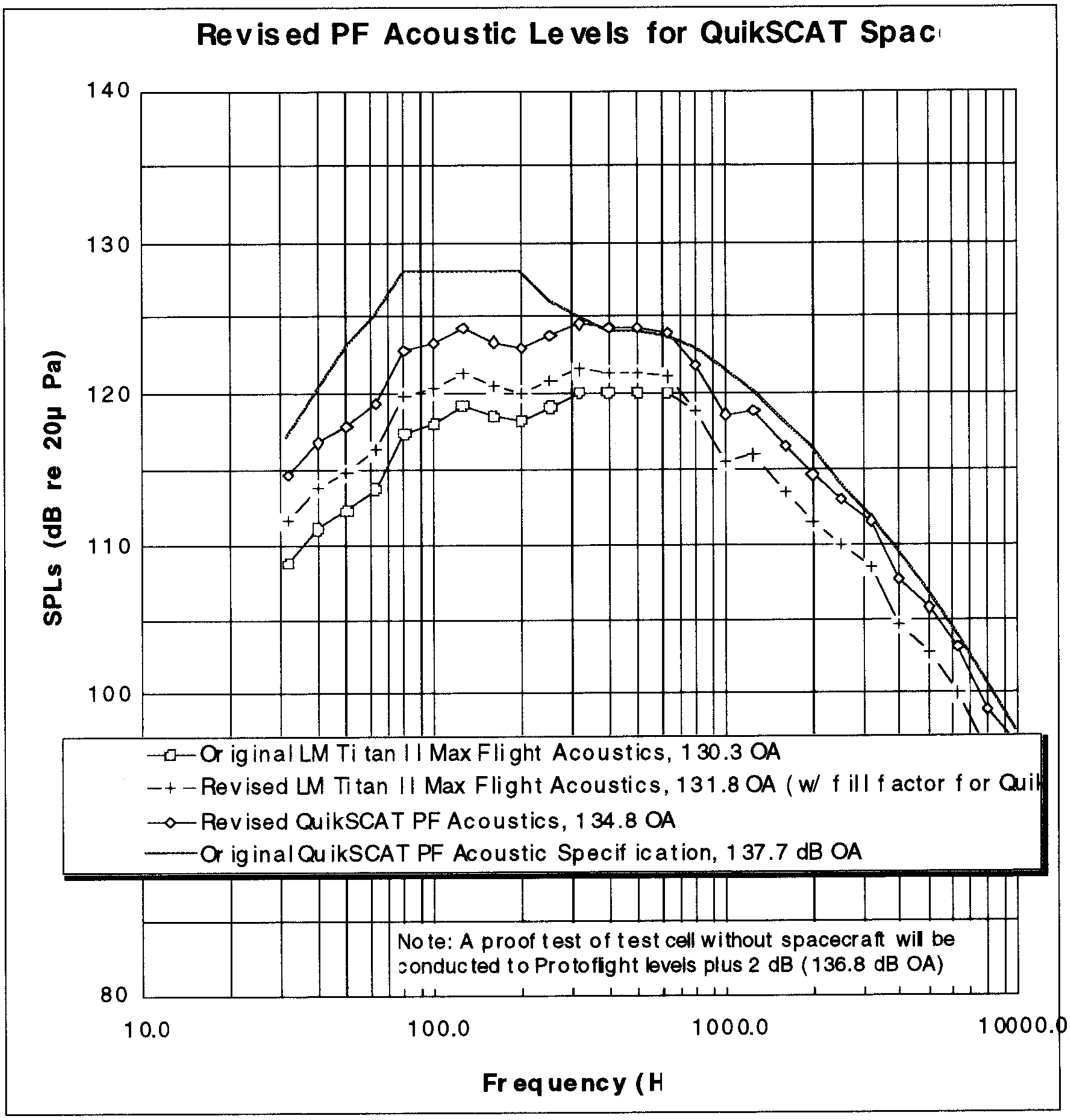

Figure 1. Full Level Acoustic Input Specification for QUIKSCAT

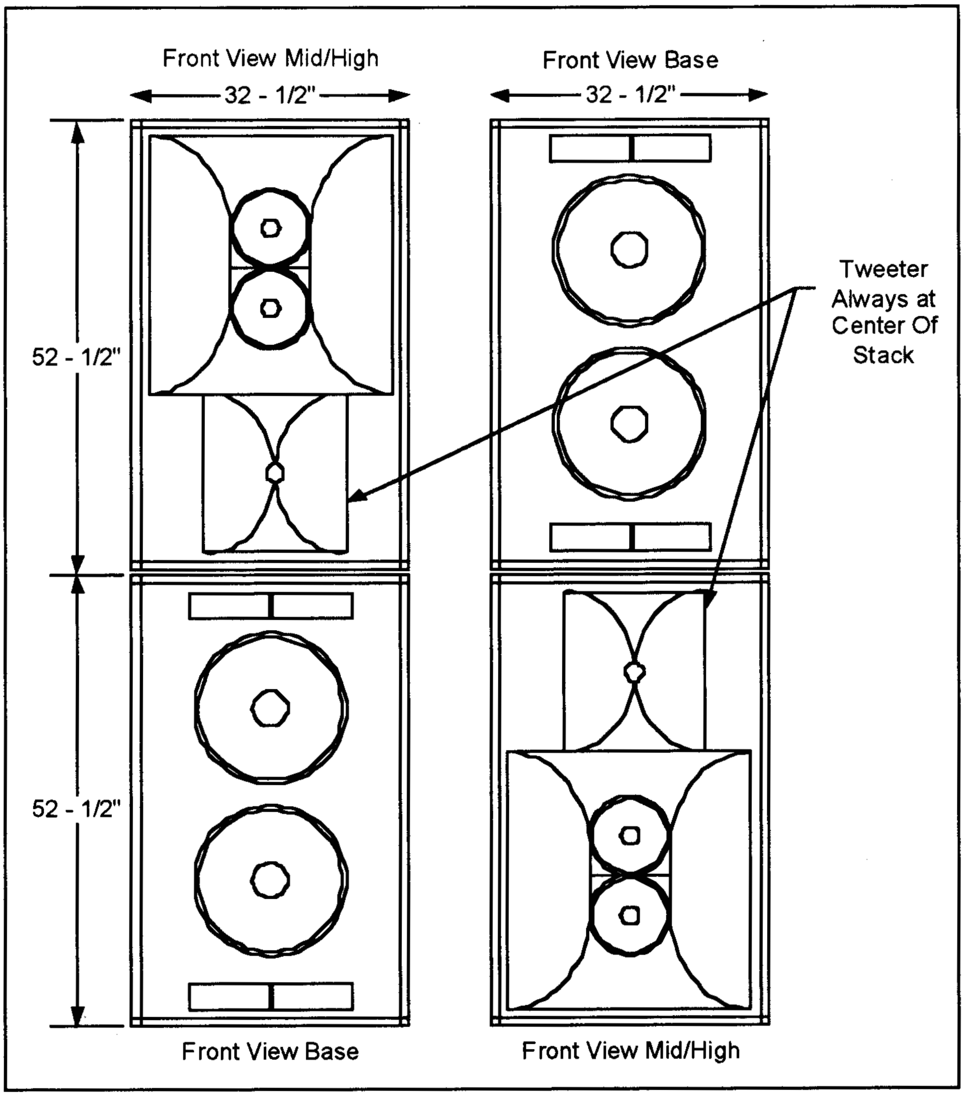

Figure 2: Alternating AALTO Mid/High and Base Speaker Cabinets On Top and Bottom Powered by Audio Analyst AALTO Amplifier Rack, Stereo Graphic Equalizer, and Pink Noise Generator

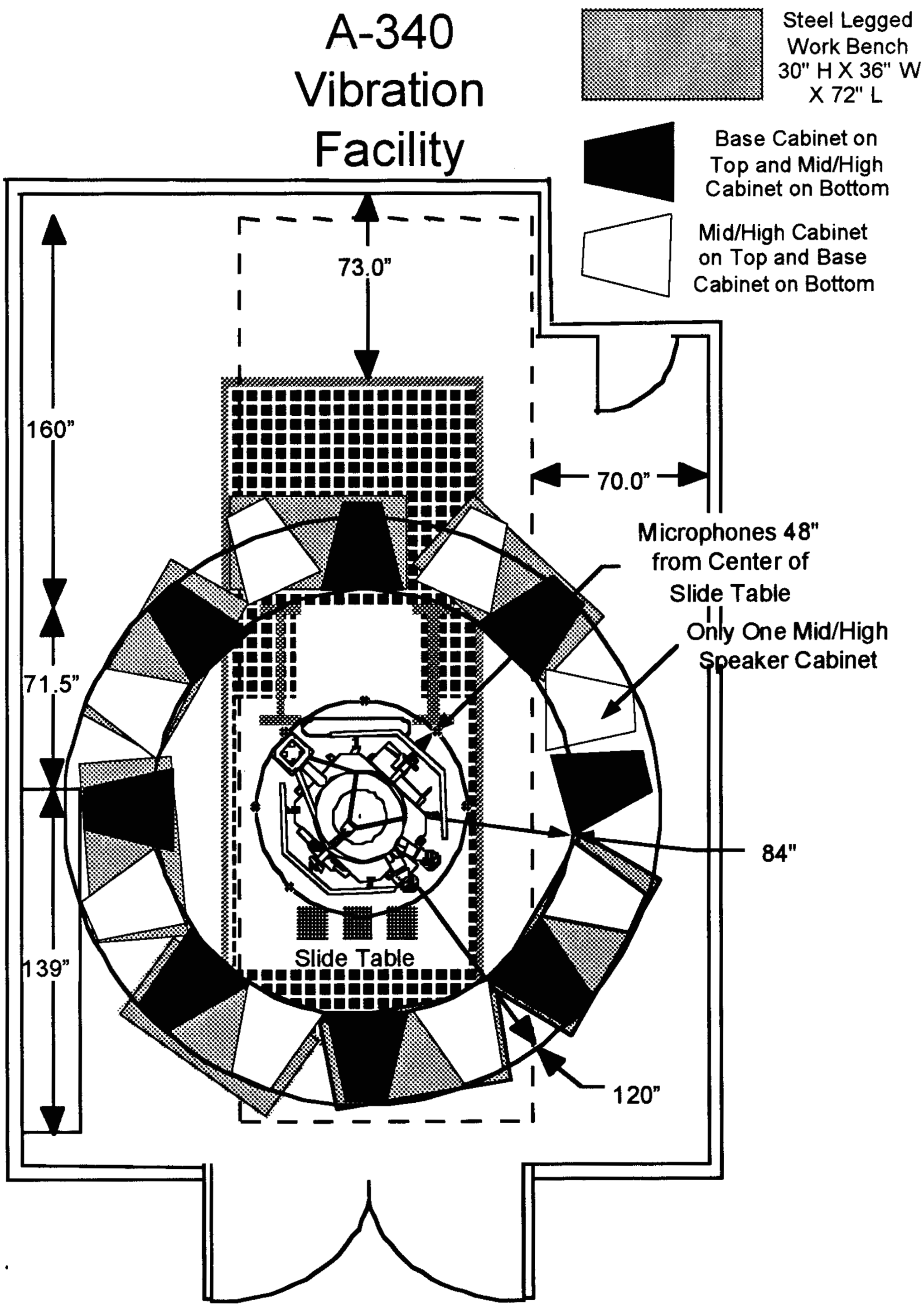

Figure 3: Speaker Cabinet Installation in Ball Areospace's A-340 Vibration Chamber

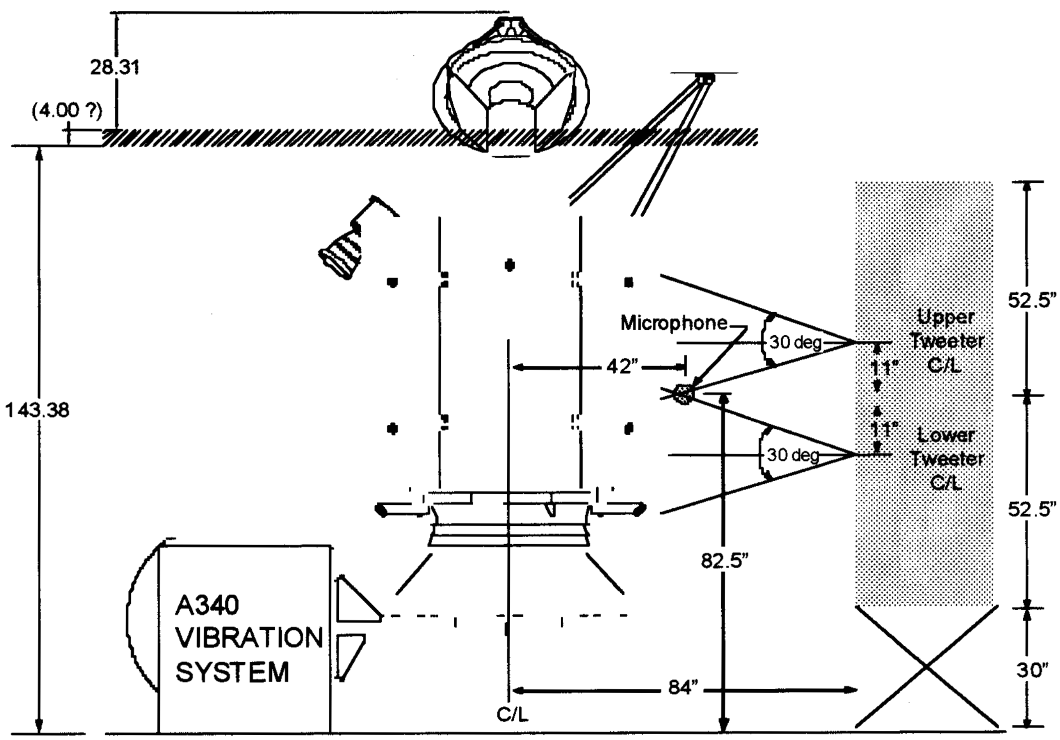

Figure 4. Elevation View of Set-up for Acoustic Test of QuikSCAT Spacecraft

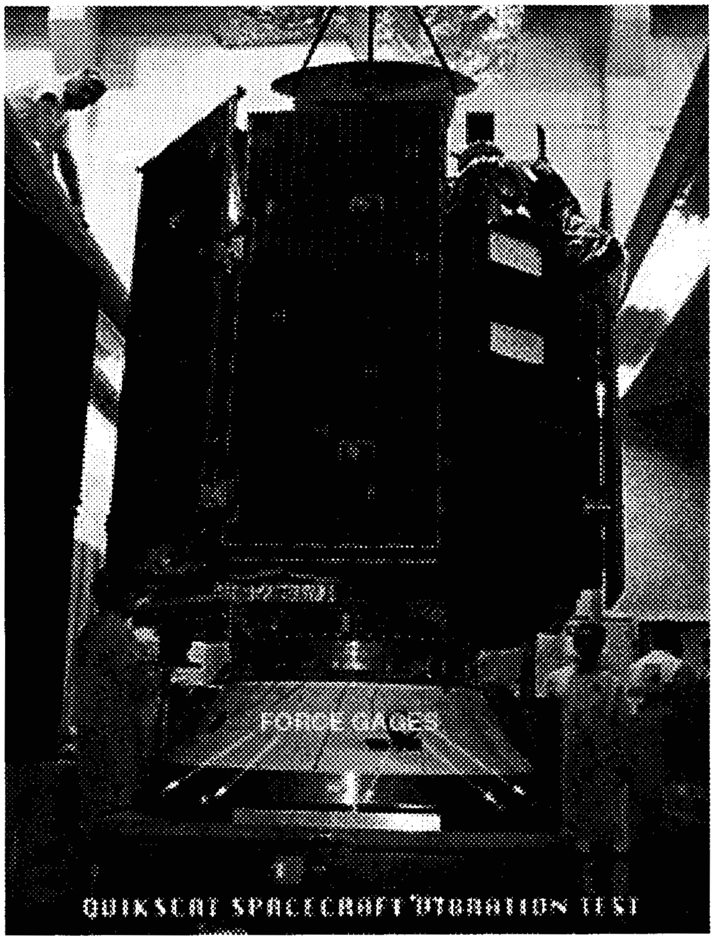

Figure 5. QuikSCAT Spacecraft Being Lowered into Vibration Test Cell at BATC

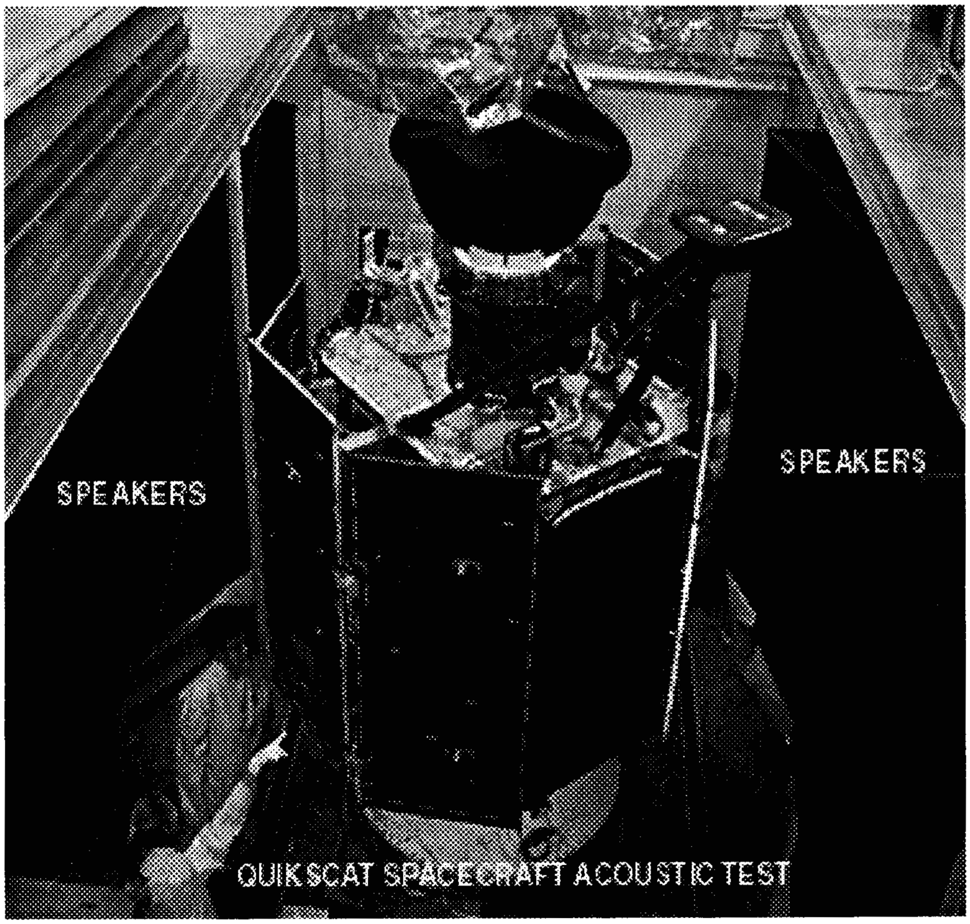

Figure 6. QuikSCAT Spacecraft with Speakers in Test Cell at BATC

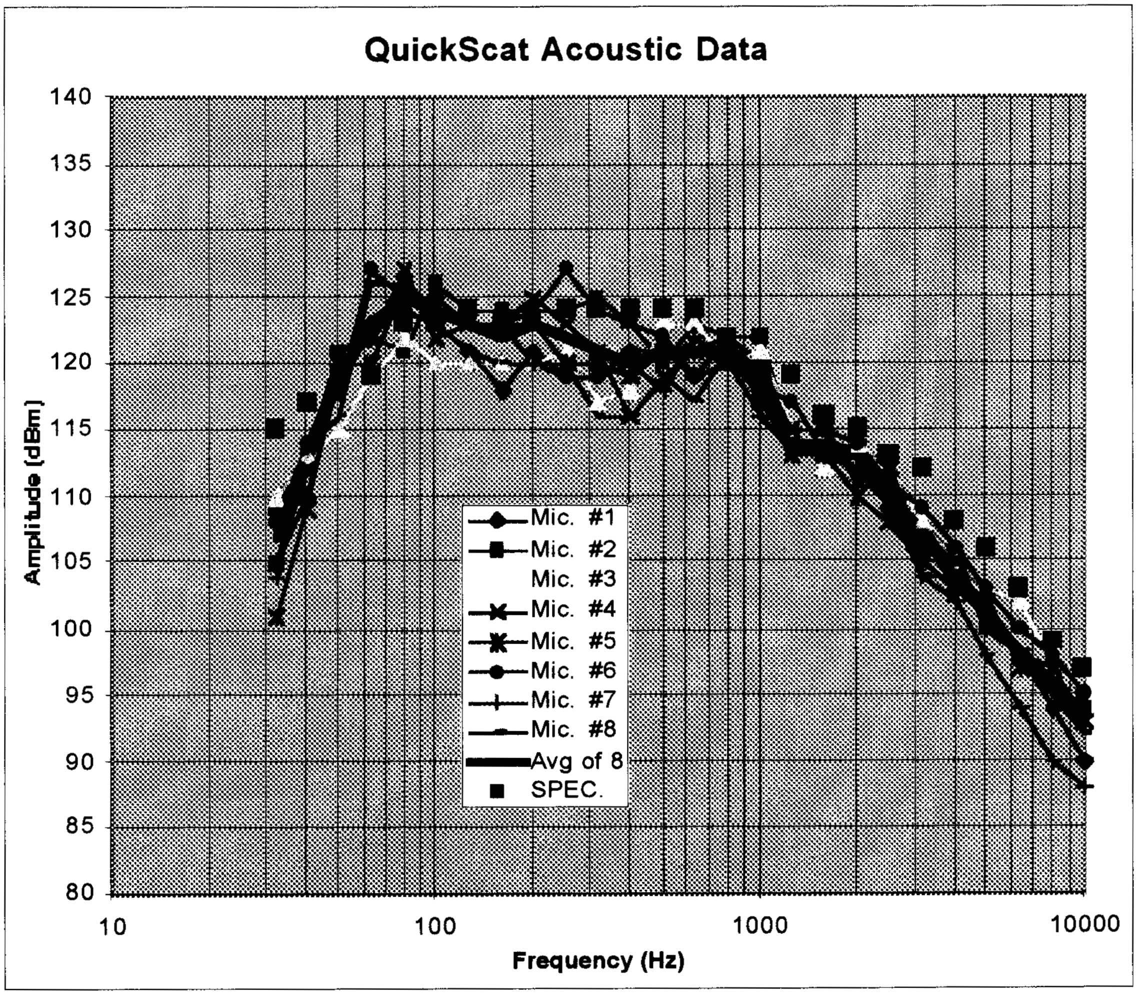

Figure 7. Comparison of Eight Microphone and Specification Acoustic Levels

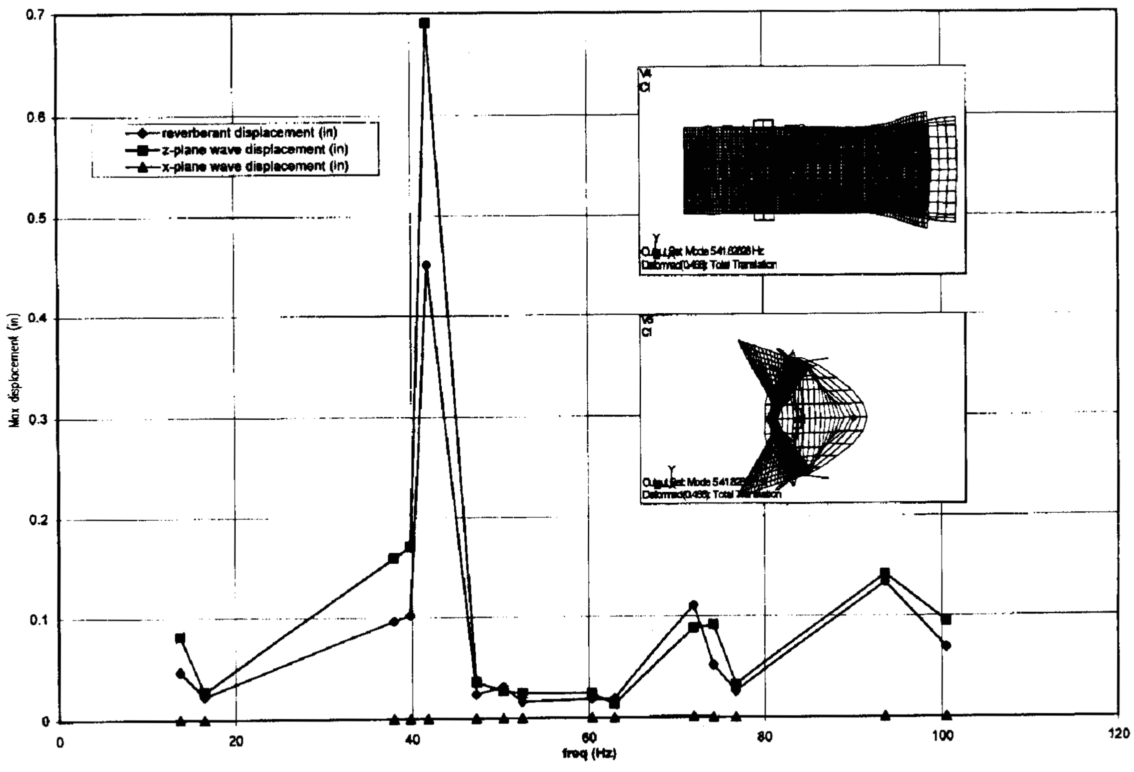

Figure 8. BEM Calcualation of the Response of a Solar Panel Reflector to Normal, Grazing, and Reverberant Acoustic Excitation